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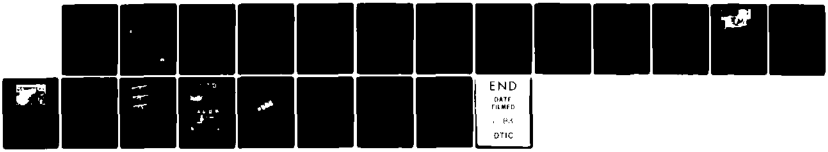

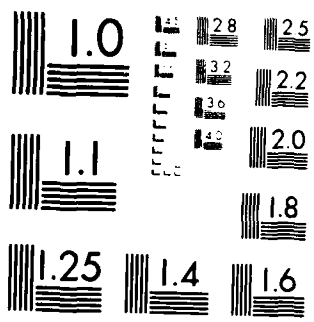

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Special Report 79-33

October 1979

A TEST OF SNOW FORTIFICATIONS

De[illegible]. Farrell

Prepared for
DIRECTORATE OF MILITARY PROGRAMS
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A field study was conducted to 1) more accurately define the degree of protection offered by simple snow fortifications and 2) evaluate the effort required by infantry troops to build such fortifications when only basic tools are available. A seven-man infantry squad equipped with standard issue snow shovels and an arctic sled (Akhio) constructed several simple snow structures. Construction was made more difficult by the imposition of a camouflage discipline requirement. When completed, three positions were subjected to M16A1 rifle fire while the infantry squad executed a simulated tactical assault. A fourth and much larger position was tested with simulated covering fire from an M2HB 50-caliber machine gun. None of the 5.56-mm bullets fired by the squad from ranges of 200 m to as close as 10 m managed to penetrate the 1.8-m-thick snow embankments. The 12.7-mm-diameter bullets fired from the

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M2HB at a range of 250 m were all stopped by 3.0 m of packed snow. The camouflage considerations and the shallow snow conditions increased the construction time for the three small emplacements by almost a factor of four, and for the larger emplacement by almost a factor of three. But the squad still handled a volume of packed snow that was equal to 3-7 times the volume of unfrozen soil that could be handled with the same amount of effort, according to field manual estimates. Under frozen soil conditions the advantages of using snow would be significantly greater.

PREFACE

This report was prepared by Dennis R. Farrell, Mechanical Engineer, Civil Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory.

The study was funded under DA Project 4A762730AT42, *Design, Construction and Operations Technology for Cold Regions*; Task A1, *Ice and Snow Technology*; Work Unit 005, *Construction Techniques for Expedient Protective Structures Using Cold Regions Materials.*

G.W. Aitken and Dr. G.K. Swinzow of CRREL performed technical reviews of the report.

The author especially thanks Mr. Aitken and Dr. Swinzow for encouraging him to perform the study, and E. Roecker of Ballistic Research Laboratory for furnishing reports and explaining BRL's work in firing small arms into gelatin.

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INTRODUCTION

Recent literature on modern battlefield tactics predicts an environment of intense military activity and decisive engagements. The time frame projected for victory or defeat is drastically condensed compared with that of historical engagements. This viewpoint is expressed convincingly in the Department of the Army Field Manual FM 100-5, *Operations* (HQ, DA 1976), which is the capstone of the Army's system of field manuals. Three examples of this viewpoint are:

1. "The first battle of our next war could well be its last battle: belligerents could be quickly exhausted, and international pressures to stop fighting could bring about an early cessation of hostilities. The United States could find itself in a short, intense war -- the outcome of which may be dictated by the results of initial combat. This circumstance is unprecedented: we are an Army historically unprepared for its first battle. We are accustomed to victory wrought with the weight of materiel and population brought to bear after the onset of hostilities. Today the U.S. Army must, above all else, prepare to win the first battle of the next war."
2. "Our Army must expect to fight its battles at the end of a long, expensive, vulnerable line of communications. Forward deployed forces, and those reinforcements immediately available, must therefore be prepared to accomplish their missions largely with the resources on hand. They must anticipate combat against forces with ultramodern weapons, greater numbers, and nearby supply sources. Winning will rest predominately with commanders of engaged forces. The U.S. Army must prepare its units to fight outnumbered, and to win."
3. "U.S. Army combat development seeks to increase the Army's ability to fight decisively by searching combat experience, experiments, tests, and technology for ways to provide better weapon systems, organizations, tactics and techniques. Success in combat developments is vital for our success in battle."

These predictions put increasing pressure on the preparedness of today's soldier. Time may not permit him to adapt to unanticipated conditions on the battlefield. An awareness of not just one solution, but several alternative solutions, to a task is becoming more important. Expedient construction of field fortifications is a task requiring such alternative solutions.

History has shown that in some cases weather influences tactical decisions more than the actions of the enemy. In this respect, a winter environment is one of the most demanding on the resources of a soldier. A snow cover affects his mode of travel and his choice of cover. The cold weather changes the clothes he wears and the shelter he erects. The depth of frost in the soil may influence his decision to build defensive positions above the ground or in the ground.

This report discusses expedient construction of one or two-man fortifications using snow and frozen soil. It outlines the advantages and limitations of fortification construction using these materials in terms of the protection they provide against small arms fire and the time required to construct the fortifications.

This report also describes the results of:

1. A field test (phase I) conducted at Camp Ripley, Minnesota, in which 5.56-mm and 12.7-mm-diameter bullets were fired at fortifications constructed from snow. The tests were conducted in simulated combat conditions at ranges up to 250 m. Previous tests were all done at close range.
2. A field test (phase II) conducted at CRREL in which 5.56-mm and 7.62-mm-diameter bullets were fired from close range and at different angles into the smooth surface of a snow embankment to determine the influence of impact angle on bullet behavior.

Finally, this report reviews the results of previous laboratory and field tests on frozen soil (Aitken 1979a, b)

and on snow (Johnson 1977). This develops into a discussion on the relationship between the terminal stability of small arms projectiles in gelatin (Roecker et al. 1977) and snow (Cole and Farrell 1979). The report also includes comments on the design parameters for the stability of small-caliber projectiles in air which result in instability and tumbling of the projectiles in a dense material such as gelatin, snow and frozen soil. In addition, it relates the importance of tumbling to rapid deceleration and reduction in penetration of the bullets.

Background

The work described here was part of an overall investigation of materials that are available in cold regions for building expedient protective structures.

The objectives of the overall program were to determine:

1. What changes subfreezing temperatures cause in the protective properties of materials.
2. What modifications to construction techniques are required to build conventional protective structures in a cold environment.
3. How materials such as ice, snow and frozen soil could best be used as building materials, both alone and in combination with other materials.

The studies reported here address the latter objective.

Swinzow (1972) reported penetrations of small arms projectiles and steel spheres into compacted snow. He observed that ogive-shaped projectiles from small-caliber rifles tumble in snow and that the physical relationship between penetration of bullets and material properties of the targets is very complex.

In 1974, CRREL completed its Terminal Ballistics Facility; this facility was described by Farrell (1979). Aitken (1979a, b) presented data on blunt-shaped, fragment-simulating projectiles that were fired into snow and frozen soils. He also presented data on 7.62-mm bullet penetrations in frozen soil. Using some of the most recent analytical techniques for predicting penetrations, he found good correlation between measured penetrations in both snow and frozen soil for the fragment-simulating projectiles. He explained that these projectiles, which had flat frontal surfaces, showed no evidence of tumbling. For 7.62-mm (30-caliber) military rounds fired into frozen soil, he found that correlation was not as good and that it broke down completely when the rounds began to tumble above specific impact velocities.

Schaefer (1973) gave preliminary data on the penetration of several U.S. infantry weapons in packed snow. These weapons included the M16A1 rifle (5.56 mm), M60 machine gun (7.62 mm), 50-caliber machine gun (12.7 mm), M79 grenade launcher (40 mm), and 90-mm recoilless rifle which was used to fire shaped charge antitank rounds. Johnson (1977) expanded on Schaefer's field tests with the three small-caliber weapons. Farrell (in prep.) expanded on Schaefer's work with the 90-mm recoilless rifle.

In general, these investigations showed that, in frozen soils, penetration of all types of projectiles tested was significantly less than in unfrozen soils. In both snow and frozen soils, penetration increased as impact velocity increased until projectile deformation, instability, or a combination of the two caused a decrease in penetration at the higher velocities.

Foreign technology

A literature survey on winter tactics and field fortifications was requested from the U.S. Army Foreign Science and Technology Center (FSTC). The literature obtained through this survey summarizes Soviet field construction capabilities and tactics during the period 1960-75. In general, most of the illustrations of recommended field fortification construction techniques appear overly complex and labor-intensive except for the fortifications constructed in deep snow, i.e., > 50 cm deep. At this depth, snow is the primary construction material. At snow depths between 20 and 50 cm, a combination of excavated soil and packed snow is recommended for construction of parapets if the ground is not too hard and the frost penetration is not too deep. At snow depths of less than 20 cm, use of snow is recommended only for camouflage.

The literature also contains examples of studies of the protection that snow provides. The following quotation is taken from an article that appeared in the November 1975 issue of the Finnish Army Engineer Magazine *Pickaxe* (1975), which describes the results of tests carried out at the training area at Sarriöjärvi, Finland, in the winter of 1975. Under the heading of "Snow" the article says:

> "Snow is not only a drawback but also an advantage. The protective value of a dug-out constructed in snow and a trench one can advance through by crawling should not be underestimated, although its greatest advantage is that it can be built quickly. Construction of a dug-out in the ground takes about eight times longer than to dig into the snow. In a minor scale test series the purpose was to clarify the capacity of snow not treated or packed and not mixed with soil to provide protection against *rifle caliber bullets*. It was concluded from the results that the density of snow and the penetration of bullet followed the following formula:
>
> $$P = (3.0\text{-}3.6\cdot\gamma)\ 100$$
>
> where: P = penetration of a bullet (cm)
> γ = density of snow (g/cm^3).

The density of snow, especially in early winter, may be 0.2 gm/cm³ which gives a penetration figure 210...240 cm. On the other hand it revealed that it is important to increase the snow density. The test series are valuable enough to be continued."

Johnson's (1977) penetration data for the M60 machine gun and the M16A1 rifle are compared with the Finnish equation in Figure 1. The graph suggests that the "rifle caliber bullets" were from 7.62-mm weapons similar to the M60 machine gun. A power regression was used for curve fitting of Johnson's data to obtain the equations shown.

The *Pickaxe* article also recommends that winter field fortifications be built in stages by using the most available materials first (snow is recommended) to achieve marginal protection, then by using the materials requiring more labor as time permits.

The best available information on Soviet concepts of fortification construction in cold regions is contained in a Soviet field manual *Engineer Organization of a Rifle Co. in a Defensive Area* (Belokon 1960). The instructions for building a one-man foxhole are as follows:

> "In digging in, one-man foxholes are made by throwing out the snow to the required depth. The parapet of the foxhole is made from packed snow. With a depth of snow of 50-60 cm, a foxhole for firing from the kneeling position is dug at once. A foxhole for firing from the standing position is dug in the snow and partially in the ground with the indicated thickness of snow cover. The dirt which is taken out in digging is used for the construction of the parapet which, upon completion of the work, is camouflaged with clean snow. Such a foxhole [shown in Fig. 2] is dug by a rifleman in 3.5-4 hours. However, in view of the difficulty in working frozen ground, a one man foxhole for firing from the standing position is made most often by creating a higher parapet from packed snow. Subsequently, just as under summer conditions, a trench is dug for a rifle squad by connecting the one man foxholes with each other with a communication trench which has been dug out in the snow."
>
> "With availability of sufficient forces and time, it is always desirable to begin to dig the trenches and communication trenches immediately after digging in. Depending on the depth of the snow cover, the trenches are dug either completely in the snow [Fig. 3] or partially in the snow and partially in the ground[Fig. 4]."
>
> "In deep snow which permits digging a trench to full depth or somewhat less (for movement bent over), first we clear away the snow to the planned mark of the bottom of the trench pit. Then we face the front and rear slopes of the trench with layers of clumps of snow, ice, or clumps of frozen ground, sprinkling them with loose snow and with a subsequent leveling out and packing. If there is a reservoir nearby, it is recommended that each row of clumps of snow and sprinkled snow be sprinkled with water during the construction of the trench. In loose snow and in the absence of clumps of frozen ground or ice, the slopes of a snow trench are made with a wooden lining."
>
> "The parapet of the trench is faced to a height of 30-40 cm. If the parapet is made from moist, tightly packed snow, its thickness is brought to 1.5-2.0 meters. With looser snow, the thickness of the parapet is increased to 3.5 meters."
>
> "The work in digging a trench in dirt --- two soldiers are given one crowbar (or heavy pick mattock) and two shovels and a sector of trench 4-6 meters long is designated. Working in turn with the crowbar (pick mattock) and shovel, the soldiers first loosen up and throw out the frozen ground and then, by layer, they dig out the thawed ground with sapper shovels to the required depth. It is extremely important that work be conducted continuously on each section of the trench since, when halting, the thawed ground which is beneath the frozen crust freezes quickly and hinders the work. For the

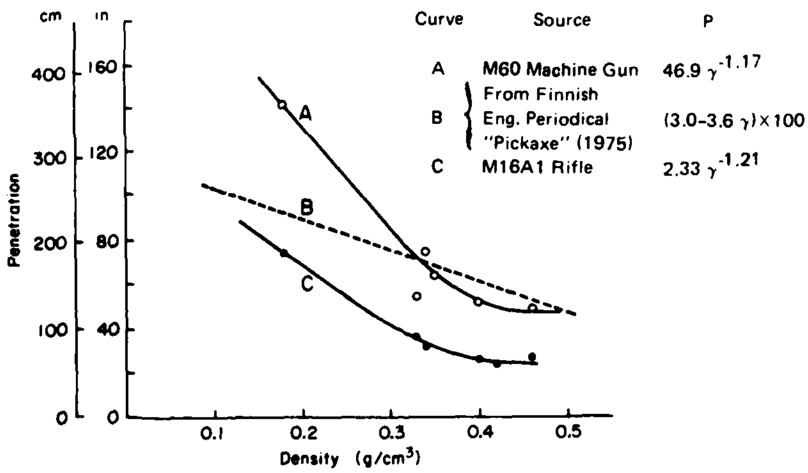

Figure 1. Penetration for Finnish and CRREL field tests in snow.

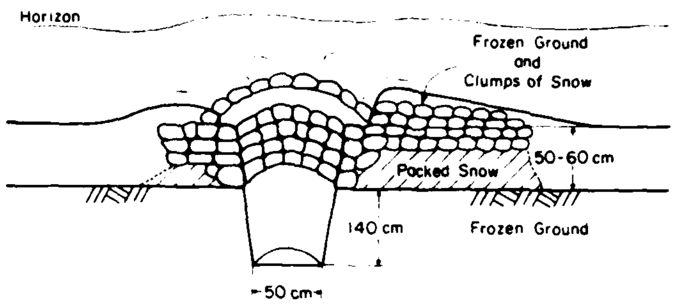

Figure 2. One-man foxhole dug partially in the snow and partially in the ground (from Belokon 1960).

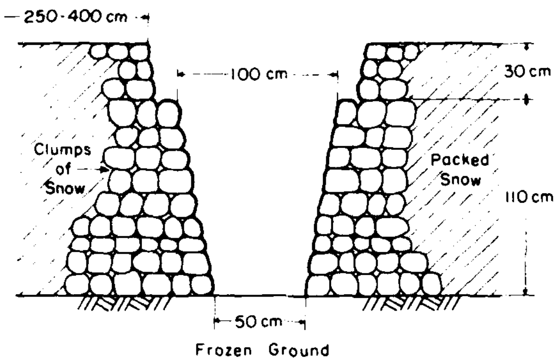

Figure 3. Making a trench in snow (from Belokon 1960).

same reason, it is expedient to place the dirt which has been dug out in the parapet immediately. After completion of digging the trench, the entire section is camouflaged by a layer of snow."

"The productivity of labor of one soldier in digging out a trench in frozen ground manually is 2-2.5 running meters in 8 hours. Consequently, about 450 man-days are required to dig one kilometer of trench. Such an expenditure of labor."

Despite this acknowledgment, the pages following the above section in the field manual contain many examples of elaborately constructed underground positions that were used during World War II.

PHASE I TEST PROGRAM

Purpose and objective

The purpose of the test conducted at Camp Ripley for this investigation was to evaluate the performance of fortifications constructed from snow under conditions approximating those of a combat environment. The evaluation included both the methods of construction and the performance of the fortifications against small arms fire.

Results of previous laboratory and field tests conducted at short range were used to specify the dimensions of the fortifications, since by being consistent with previous studies any change in snow fortification performance would be detected.

Test preparations

Before the test at Camp Ripley, a rehearsal without weapons was conducted to familiarize the squad members and the CRREL cameraman with the test plan. It became apparent that some margin of safety would be sacrificed if the assault was conducted while the troops were running; unseen protrusions or depressions hidden beneath the snow could easily cause the men to stumble and fall while firing their weapons. Therefore, the pace of the troops was slowed and they were restricted to semi-automatic fire. Both of these restrictions undoubtedly increased accuracy of the fire and the severity of the test.

Also, during the rehearsal it was realized that camera coverage would be difficult if a flanking maneuver was used. For safety, the cameraman's position would have to be located further to the rear and his field of view

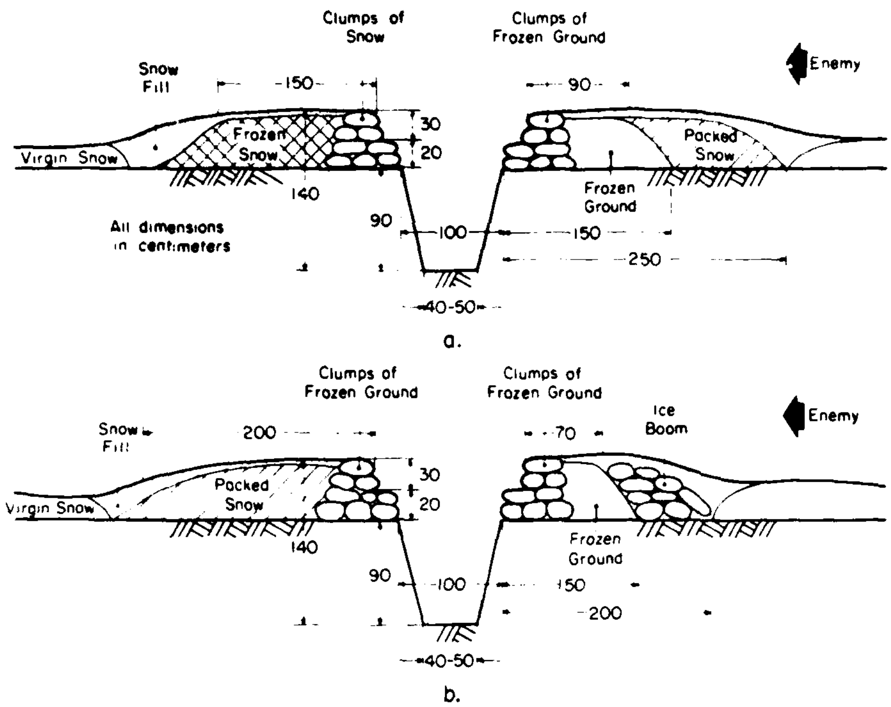

Figure 4. Variations in making a trench in frozen ground (from Belokon 1960).

could not cover more than small portions of the action. Therefore, it was decided to use a frontal attack.

The freedom from flanking fire also permitted a simpler design of the fortifications. This was desirable because the study had lower priority than other troop training exercises and had to be concluded during a two-week training period.

Construction of snow fortifications

The snow in the test area was approximately 30 cm deep with a slight wind crust and a density of 0.16-0.18 g/cm^3. In contrast, Johnson (1977) conducted his study under more favorable conditions (66-cm snow depth of 0.18-g/cm^3 density) and was not concerned with such considerations as camouflage discipline or tactical location.

For this study, an effort was also made to inject an element of realism in the construction of the fortifications by using the following controls:

1. Camouflage discipline: no snow was removed and no tracks were left that would be readily visible from the fronts of the positions.
2. Tools: only standard issue equipment was used. The three snow shovels used were a light aluminum type, 36 cm wide x 35 cm deep with a 2.5-cm high lip.
3. Tactical realism: the locations were chosen by the squad leader by applying standard military tactics with little regard for sources of snow.

After exhausting the snow supply in the immediate vicinity of each of the four fortifications, the seven-man squad adopted a system using an akhio (sled) to haul snow to the construction sites. One man packed and shaped the embankment, and two men held the canvas skirt of the akhio open while three men alternately shoveled the snow (Fig. 5). The two men who had held the skirt then dragged the loaded akhio to the site. In a real situation, the seventh man would have had guard duty.

The first three fortifications were spaced about 10 m apart and straddled a road through the platoon attack course. The snow for the fortifications was hauled 5 m to the first two fortifications and 15-20 m to the third fortification. A fourth fortification was constructed for tests with a 50-caliber machine gun. The dimensions of the four fortifications are given in Figure 6. The three smaller positions were constructed with 4.1 m^3 of packed snow and the larger fortification was constructed with 12.2 m^3 of snow for the machine gun test. Figure 7 shows the production rates for the four fortifications as well as the rates reported by Johnson (1977). At Camp Ripley, the depleted snow conditions, together with the requirement for camouflage discipline, resulted

Figure 5. Seven-man squad hauling snow for snow fortification in background.

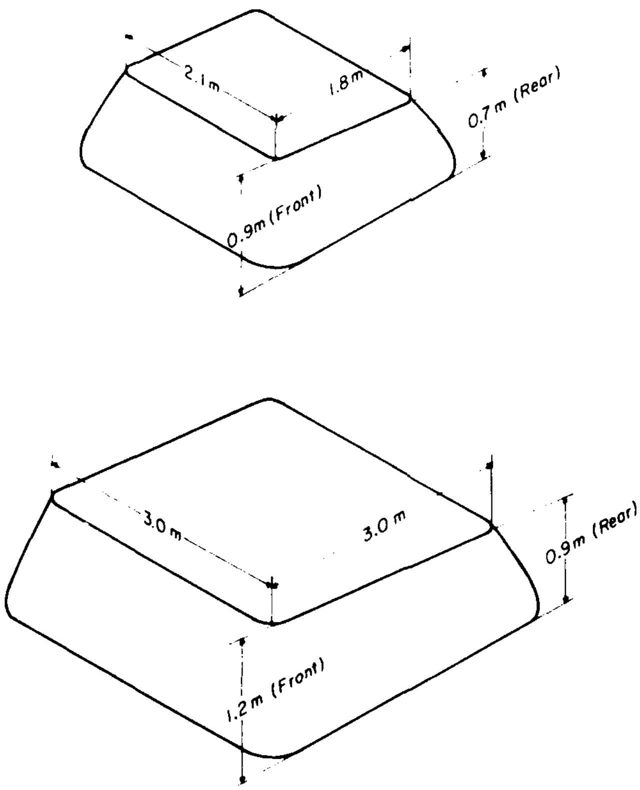

Figure 6. Dimensions of snow embankments constructed for line fire assault.

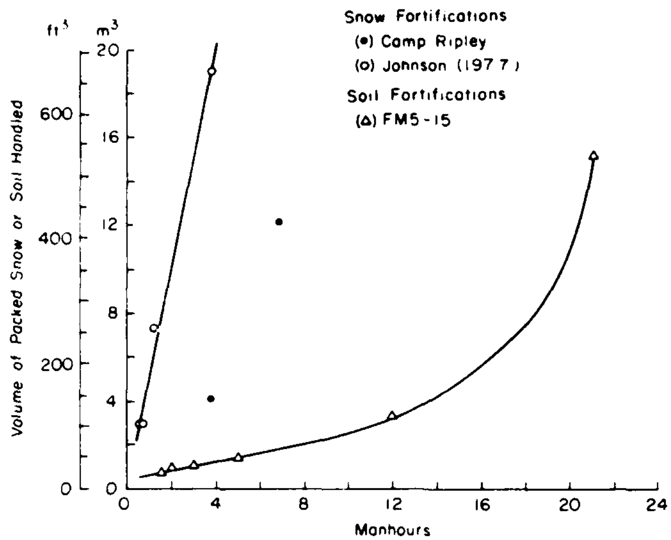

Figure 7. Volume handled vs. manhours required for snow embankments and unfrozen soil excavations.

in productivity about two-thirds less than reported by Johnson.

As a point of reference to compare the data on productivity for the snow tests, the volume of soil excavated and the time required to build expedient fortifications in *unfrozen soil* were extracted from Field manual FM 5-15, *Field Fortifications* (HQ, DA 1972). Figure 7 shows that, even under the restrictive conditions previously explained, 3-7 times as much packed snow can be handled in the same time frame.

Test plan

The plan specified two separate attacks on the three smaller fortified positions using M16A1 rifles. The squad began the attack at a range of 200 m and halted 10 m from the fortifications. They paused only at the midpoint for a controlled reloading of the weapons. Twenty rounds of 5.56-mm (M193) ammunition were issued for each man's M16A1 rifle for the first part of each attack which covered about 75 m of the approach. Thirty rounds were issued to each man for the second part. In total, 700 rounds were expended in the two assaults by the seven-man squad. The results of both assaults were registered on double-layered witness screens behind each position (Fig. 8). These 1-m high x 2-1/2-m wide screens were erected with a 30-cm spacing between the two layers. From measurements of the point of impact and the shape of each hole in both screens, estimates were made of the direction of flight and the orientation of all bullets that struck the screens (Fig. 9).

For the 50-caliber machine gun (M2HB), the original test plan specified 200 rounds, which represented a realistic figure for covering fire for a single assault. When the plan was changed and a single fortification was constructed to test with this weapon, the allotment for the *50-caliber machine gun* was lowered to *70 rounds*. These were fired from a hilltop about 15 m high and 250 m distant from the new fortification.

Test results

Of the 700 5.56-mm rounds fired from the M16A1 rifles at the three smaller positions, 609 of the rounds (87%) either stopped in the snow or went wide of the witness screens. Of the 91 rounds that did hit the witness screens, 63 cleared the positions altogether. This was indicated by the path of the bullets through the witness screens and stable flights indicated by lack of tumbling. Only 28 rounds (4% of the total) passed through snow before hitting the screens. As Figure 9 illustrates, these rounds were distinguished by a keyhole-shaped puncture and usually a rising flight path indicating deflection by the snow (broaching). Two of these rounds appeared to have hit the side of the fortification and struck the screens near the fringe of the area that was shielded by the snow. None of the bullets penetrated the 1.8-m thickness of the snow.

The test using the 50-caliber machine gun (M2HB) was less conclusive. Of the 70 rounds fired, only 8 (11%) struck the 1-m high x 3-m wide witness screen and a similar number hit the position. No rounds penetrated the 3-m-thick embankment.

Figure 8. Witness screens behind small snow embankment.

PHASE II TEST PROGRAM

Purpose

The purpose of this study was to obtain preliminary data on the broaching characteristics of bullets fired from small arms weapons. The weapons were chosen for their unique features of external ballistic design. The tests were conducted in the field and the intent was to collect enough information to define the requirements for a future laboratory study.

For the test a Communist bloc AK47 rifle and an M16A1 rifle were received on loan from the 10th Special Forces Group at Ft. Devens, Massachusetts. An M14 rifle was already on hand. These are shown in Figure 10.

Snow embankment construction

The snow embankments were constructed with a snow blower. Production rates are not given because the snow was cycled twice to break up a thin melt crust. Two snow embankments (3/4 m high× 1-1/2 m wide× 30 m long) were shaped with shovels. The mechanical processing and warm air temperature (0 to -3°C) produced a dense snow of 0.4 to 0.5 g/cm^3 with an exceptionally high hardness of 5-25 kg/cm^2. All measurements were taken according to procedures outlined by SIPRE (1954).

Test procedures

The three weapons were fired horizontally at one end of the embankment of snow, as shown in Figure 11. After each series, the embankment was dissected and fresh snow was exposed for the next test.

Vertical slots, 3-5 cm wide, were made with a chainsaw at 30-cm intervals and at right angles to the bullet trajectories. Paper sheets were inserted as witness screens. The outline of the mound was marked on each witness screen.

On the front face of the embankment, both vertical and 45° cuts were made with a handsaw. For the vertical face of snow, 10 rounds were fired in each test. For the 45° impact angle, 6 shots were fired in a horizontal row at a specified distance from the top of the embankment to maintain the 30-cm spacing between the point of impact and the first vertical witness screen.

Tests with the three weapons were also conducted at a shallow impact angle on the top of the embankment. A gunner's quadrant was attached to each weapon as it was being fired to determine the angle of impact to within 20 mils (±1.25°) of the desired 250-mil (14°) angle of impact.

Test results

Data from the tests with bullets fired horizontally into the snow are presented in Table I. The test conditions were not controlled closely enough to detect the slight differences in maximum penetration of the three types of ammunition fired from the two 30-caliber (7.62-mm) weapons (types M80 and M59 from the M14 rifle and type M43 from the AK47 rifle). All of these rounds penetrated about 90 cm at both 90°

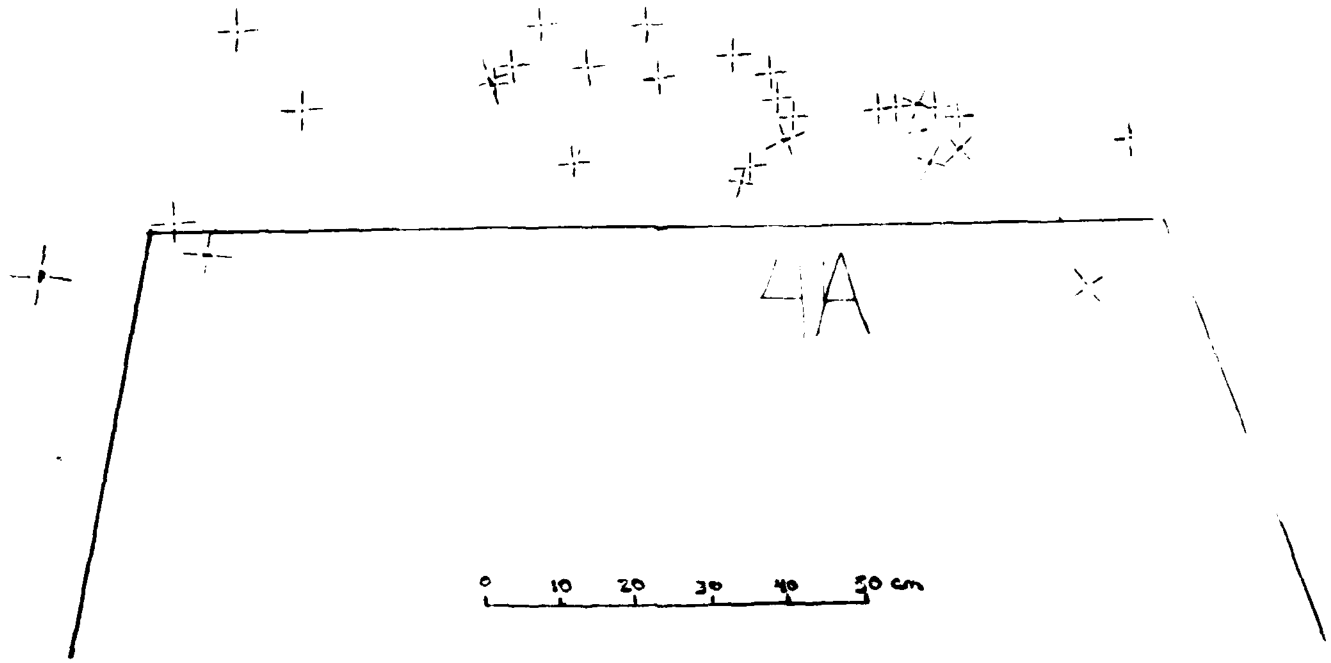

Figure 9. Witness screen showing typical results of live fire assault.

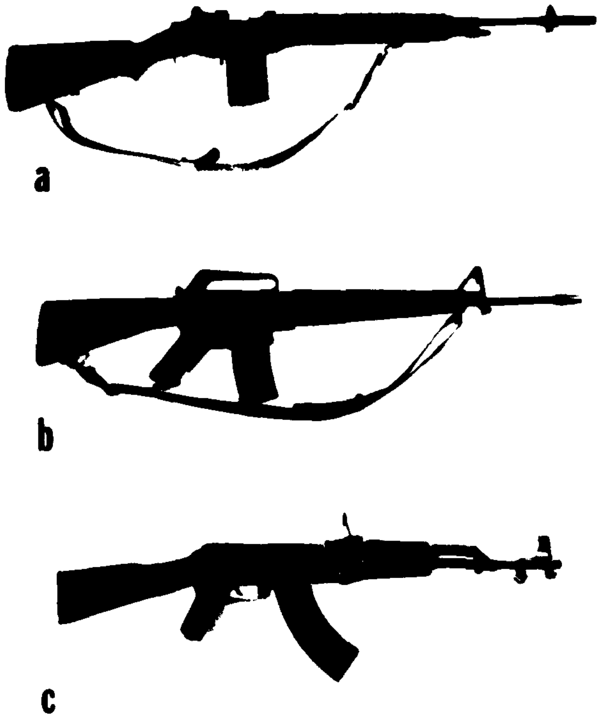

Figure 10. Test weapons for Phase II.

Table 1. Results of tests in dense snow using M16A1, M14 and AK47 Rifles at 90 and 45° impact angles.

Test no.	Snow density (g/cm³)	Air temp (°C)	Weapon	Type and no. rds. fired		Impact angle (°)	No. of rounds penetrating screens at: 30 cm	60 cm	90 cm	Deformation
T1	0.464	-4	M14	M80	10	90	10	10	4	No
T2	0.440	-4	M14	M80	10	90	10	10	5	No
T3	0.408		M14	M59	10	90	10	10	0	No
T4	0.448	-7	AK47	M43	10	90	10	10	0	No
T5			M16A1	M193	10	90	10	3	0	Yes
T6	0.470	-8	M14	M59	6	45	6	6	0	No
T7	0.516	+2	M14	M80	6	45	6	6	1	No
T8	0.496	-4	AK47	M43	6	45	6	6	3	No
T9	0.424	--	M16A1	M193	6	45	6	3	0	Yes

a. During practice firing with AK47 rifle.

b. After test with M16A1 rifle.

Figure 11. Vertically cut face of snow embankment.

Table 2. External ballistics of small arms.

	M16A1 Rifle	*M14 Rifle*	*AK47 Assault Rifle*
Caliber	5.56 mm	7.62-mm NATO	7.62 mm
Round designation	M193	M59* and M80	M43
Bullet weight	55 grains	150 grains	122 grains
Muzzle velocity	990 m/s (3250 ft/s)	853 m/s (2800 ft/s)	710 m/s (2330 ft/s)

*M59 has a mild steel core; bullet is longer to attain same weight as denser lead core in M80.

Figure 12. Deformed 5.56-mm (Type M193) and undeformed 7.62 mm (Type M43, M80 and M59) bullets recovered from Phase II tests.

and 45° angles of impact despite some differences in the external ballistics of the bullets (Table 2).

The M193 (5.56-mm) ammunition fired in the M16A1 rifle was less effective, with an average penetration of approximately 60 cm. Again the influence of the two angles of impact was not detectable. All of these 5.56-mm-diameter bullets were flattened as shown in Figure 12. None of the 7.62-mm-diameter bullets were deformed.

Measurements at the very shallow impact angle of 250 mils (14°) were made by dissecting the trajectory of two rounds for each ammunition type fired. The results are presented in Table 3 and Figure 13. These tests showed only small curvature of the path of the 7.62-mm bullets (M14 and AK47) and virtually no deflection of the 5.56-mm bullets (M16A1) from the impact trajectory. The 7.62-mm-bullets veered slightly upwards and average penetration was reduced from 90 to 75 cm. The average penetration of the 5.56-mm-diameter (M193) bullets was reduced from 60 to approximately 50 cm with the same characteristic flattening of the bullet.

DISCUSSION OF RESULTS

Lewandowski (1970) conducted a study on the subject of projectile broaching and tabulated the critical angles of impact (the angle at which 50% of the projectiles broach) using several projectile types and target materials. A critical angle of 7 - 15° was reported for 7.62-mm, M-80 type rounds impacting on water, 11 - 13° on Eglin sand, and 14 - 16° on Wyoming Bentonite, a clay soil.

The results of the live fire tests (Phase I) show that only a very small percentage (4%) of the rounds impacted at an angle that was shallow enough to cause broaching on packed snow. The results of the phase II studies indicated that the broaching resulted from

Table 3. Penetration of bullets fired at 250-mil (14°) impact angle into dense snow (0.49 g/cm^3).

Type of rifle	Caliber (mm)	Type of round	Horizontal pen. (cm)	Depth below surface (cm)	Deformation
M16A1	5.56	M193	51	13	Yes
M16A1	5.56	M193	49	11	Yes
AK47	7.62	M43	74	10	No
AK47	7.62	M43	73	8	No
M14	7.62	M59	69	10	No
M14	7.62	M59	78	10	No

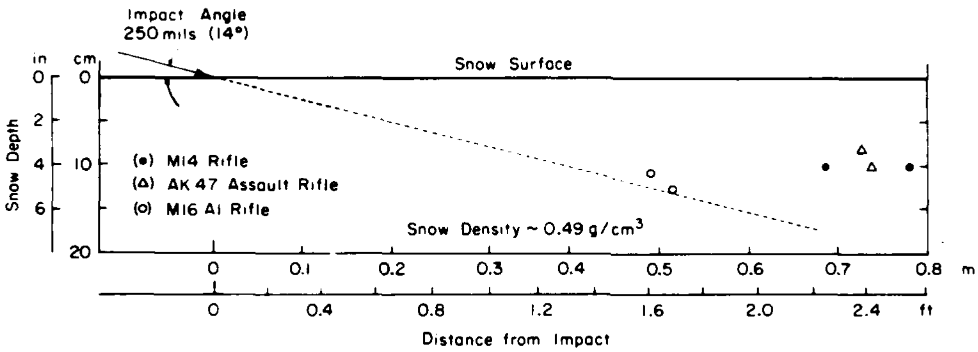

Figure 13. Penetration and deflection of 5.56 and 7.62-mm bullets in dense snow at shallow impact angle.

a very shallow angle of impact of less than 250 mils (14°). A comparison with the broaching from sand, clay and water described by Lewandowski (1970) showed that broaching in well packed snow is similar to broaching in other materials.

For the test with the 50-caliber machine gun (M2HB), the small number of rounds that struck the fortifications did not provide conclusive results.

Measurements of volumes of packed snow handled during construction showed that productivity under the limitations of shallow snow depths and camouflage discipline was two-thirds less than Johnson (1977) reported under more favorable conditions. A comparison with the production rates given in Field Manual FM5-15, *Field Fortifications* (HQ, DA 1972), for various positions in *unfrozen soil*, show that 3 to 7 times more packed snow was handled in the same time frame.

Both Russian (Belokon 1960) and Finnish (*Pickaxe* 1975) sources concur that is difficult to build even simple positions entirely from snow when the depth is less than 50 cm. At snow depths of less than 20 cm, the recommendations are that fortifications be built almost entirely from soil or other available materials. Camouflage discipline is still necessary, however, even with small accumulations of snow. The phase I tests at Camp Ripley in a 30-cm-deep snow cover showed that this guidance is realistic, but fortifications can be built by hauling snow to the site.

Schaefer (1973) and Johnson (1977) described efforts to build snow fortifications using Soviet snow block techniques illustrated in Figures 2, 3 and 4. They both concluded that these techniques were not efficient, particularly for the dry, subarctic snow found in Alaska. But during his study Johnson did demonstrate successfully the use of large burlap bags (50-lb potato sacks) filled with snow to build the vertical wall of a snow parapet. He rejected the smaller sand bags in favor of the largest bags that a man can handle easily. Schaefer tested a pile of snow blocks with an M60 machine gun. He reported that continuous fire led to collapse of some blocks and left adjacent blocks intact. He effectively punched a hole through the structure. In contrast, simple piles of packed snow collapsed after each impact. This efficiently sealed the hole and the resulting collapse of the overall structure was not catastrophic.

In the Phase II tests, the relative insensitivity of a bullet to its angle of impact was not unexpected. These tests also confirmed that bullets are unstable in a medium

as dense as snow and that the angle of impact is of secondary importance. It was also observed that tumbling bullets may wander but are not apt to veer drastically from their original trajectories. The design criteria for stable flight of spin-stabilized projectiles in air also indicated that the bullets would be extremely unstable in snow.

Figure 14 (after HQ, AMC Pamphlet 706-107, 1963) is a free-body diagram that illustrates some of the forces that act on a bullet. The equation given for drag is:

$$D = K_D \rho d^2 u^2$$

where: D = drag, lb
K_D = drag coefficient
ρ = density of air, lb/ft^3
d = bullet diameter, ft
u = bullet velocity, ft/s

Note that the drag is directly proportional to the density of the air.

This pamphlet also states:

"The condition for stability of a rotating projectile is expressed by the factor:

$$\frac{A^2 N^2}{4BM}$$

where A = the axial moment of inertia of the projectile, lb sec^2 ft
B = the moment of inertia about a transverse axis through the center of gravity, lb sec^2 ft
N = the rate of spin of the projectile, radians/sec
M = the overturning moment factor caused by air force R, and is defined as $GP\ (D + L \cot\delta)$ (ft-lb). Note that the overturning moment is $GP\ (L \cos\delta + D \sin\delta)$ and is equal to $GP\ (L \cot\delta + D) \sin\delta$.*

"The stability factor may be used to predict the degree of stability which a projectile will exhibit in flight. Projectiles having a stability factor less than *one* will be very unstable, will probably tumble, will lose range, and will produce deviations in accuracy. Projectiles having a stability factor greater than one but less than 2.5 will not tumble, will normally find the nose leading the center of gravity of the projectile throughout the trajectory, and will exhibit a desirable impact attitude for point detonating ammunition. Stability factors greater than 2.5 indicate an overstable round, one which will not track properly since the attitude of the projectile does not deviate throughout the flight (i.e., projectile lands on its base), and are found in *small arms* and high velocity anti-tank ammunition. In such instances, the high spin rate results in such slow precession that the trajectory is completed before the projectile can effectively nose down on its trajectory."

*See Figure 14 for illustration of terms.

Note that M is inversely proportional to the stability factor and is itself directly proportional to the drag R in terms of D and L, the orthogonal components of R. Knowing that the bullets under consideration have stability factors in air that are somewhat, but not significantly, greater than 2.5 (overstabilized), the stability factor for flight in snow changes in direct proportion to the ratio of densities of *air* to *snow*. The ratio is:

air density (sea level, 15°C) = 0.001225 g/cm^3
medium packed snow density = 0.40 g/cm^3

$$\text{ratio } \frac{\text{air}}{\text{snow}} = 3.06 \times 10^{-3}$$

Even assuming relatively high stability factors in air, the stability factors in snow will be several orders of magnitude below the minimum value of *one* for stability. In fact, snow is so much denser than air that these semiempirical equations for air probably do not apply. Although in-depth analysis along this line is beyond the scope of this report, the reader is referred to Cole and Farrell's report (1979) for a more detailed analysis and to Roecker et al. (1977) on a study using a target of gelatin that has a density twice that of packed snow. The inference of these equations is that any effectively designed, spin-stabilized projectile will comply very closely with the above design parameters. By doing so, they will be inherently unstable in snow.

CONCLUSIONS AND RECOMMENDATIONS

All the referenced reports that deal with targets much denser than air have either confirmed or suggested instability or tumbling of ogive-shaped bullets. The yaw angle of the bullet at the time of impact has been shown to be the most important factor determining how far a bullet will travel in a dense medium before rapid yaw growth and tumbling are initiated. Because tumbling negates the efficient geometry of a bullet, the predictability of the onset of tumbling is crucial in the selection and quantity of materials used in a fortification.

Where soil was used for fortification construction, Aitken (1979b) reported that freezing of the soil targets reduced total penetration for some projectiles by as much as a factor of four. However, since most fortifications will probably be built with unfrozen soil, either during a warm season or during a cold season, by excavating below the frost layer, opportunity to improve present construction techniques using soil is minimal. Aitken does make the observation that tumbling of bullets in soil stopped at lower velocities

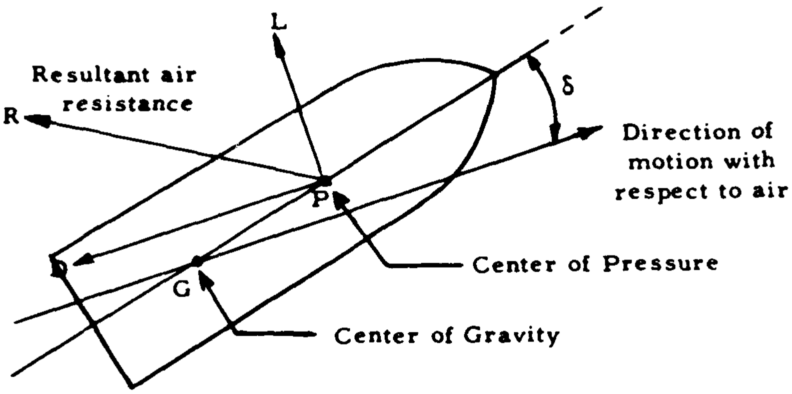

Figure 14. Free body diagram of ogive shaped projectile in flight (after HQ AMC 1963).

and penetration increased over 25%; but this is still well below the penetration in unfrozen soil.

Generally, this study has shown that: (1) fortifications constructed from snow perform favorably compared with those constructed from other natural materials; and (2) fortifications constructed of snow can be built even under adverse circumstances. Estimates of manual construction rates extracted from Soviet manuals clearly show that expedient construction of fortifications built from snow is a very attractive alternative to expedient construction of fortifications built from frozen soil.

One basic deficiency that exists in both laboratory and field studies of this type involves the relationship between bullet flight in air and its angle of yaw. Because small arms bullets are overstabilized, the yaw angle initially decreases because of the gyroscopic effect of the bullets. Then, as gravity causes an arced path, the angle of yaw increases with distance. This yaw growth has been mathematically and experimentally determined in air; but the critical angle that induces tumbling in snow at lower bullet velocites (i.e., long range) is not known.

In the CRREL laboratory facilities, the bullet velocity can be decreased, but realistic yaw conditions cannot be simulated repeatedly. Field tests, as noted, are inherently less accurate, requiring an extensive data base to draw reliable conclusions. Both the laboratory and field approaches are recommended for future studies.

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